

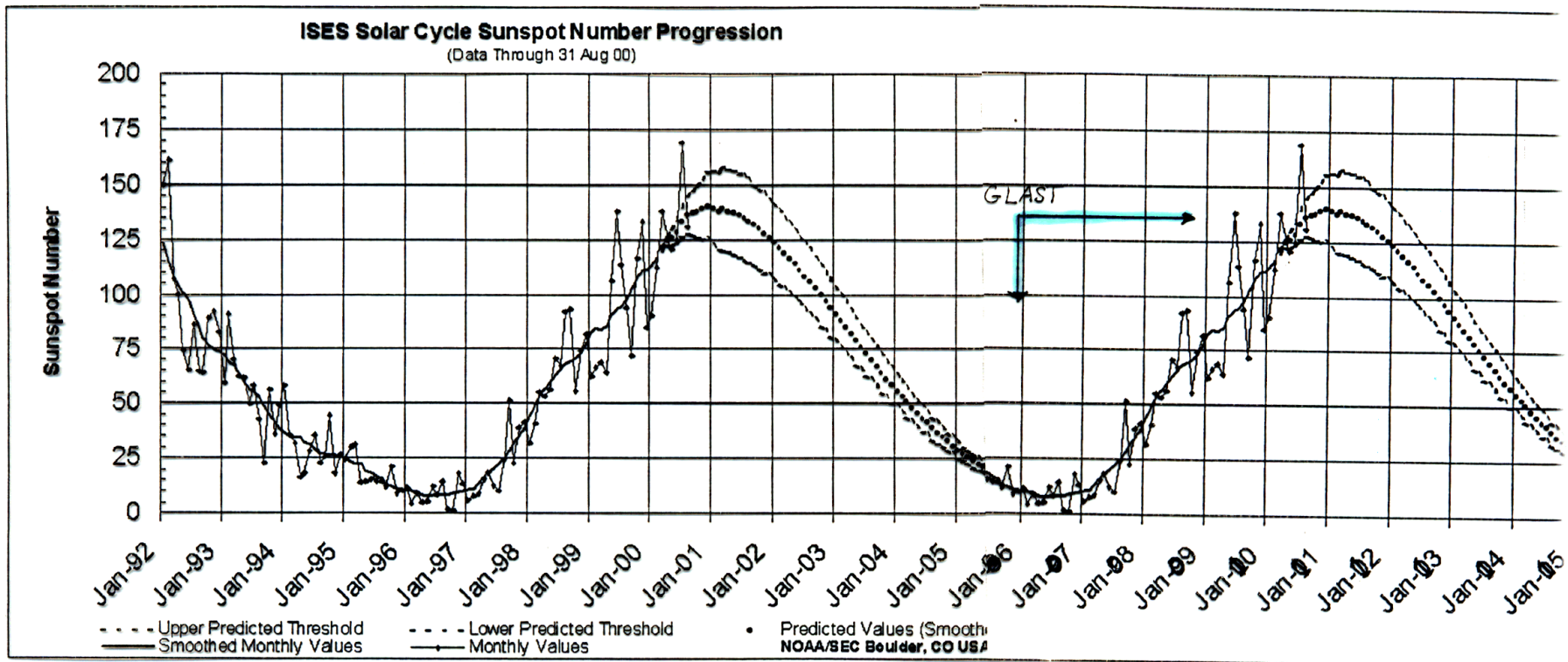
HIGH-ENERGY SOLAR PHYSICS WITH GLAST

**THE HIGH-ENERGY SOLAR EXPERIMENT
VACUUM DURING SOLAR CYCLE 24**

**SUMMARY OF GAMMA-RAY OBSERVATIONS
>10 MeV**

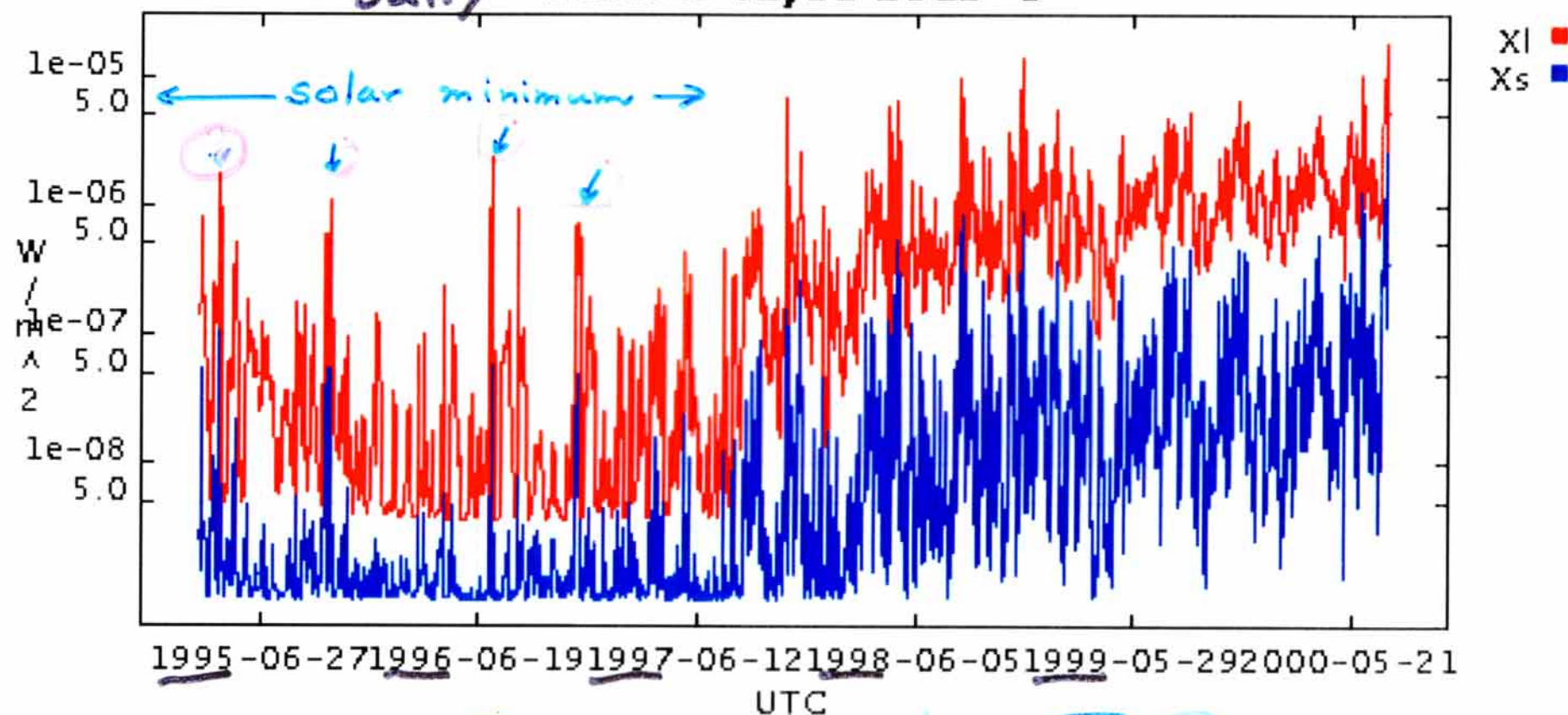
**OUTSTANDING QUESTIONS THAT
GLAST CAN ADDRESS**

**SATURATION EFFECTS DURING INTENSE
FLARES**



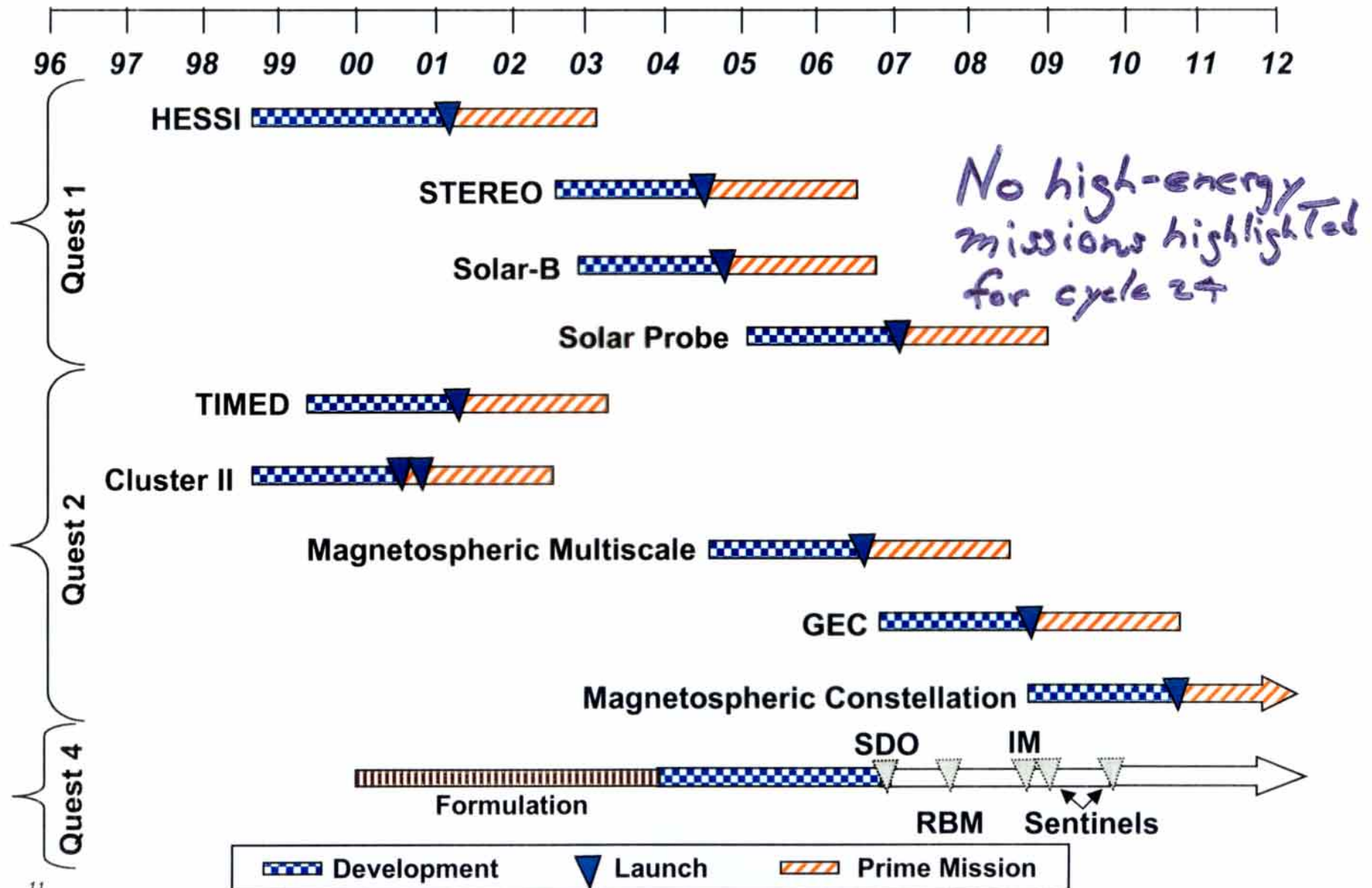
GLAST Can Observe The Rise
of Cycle 24

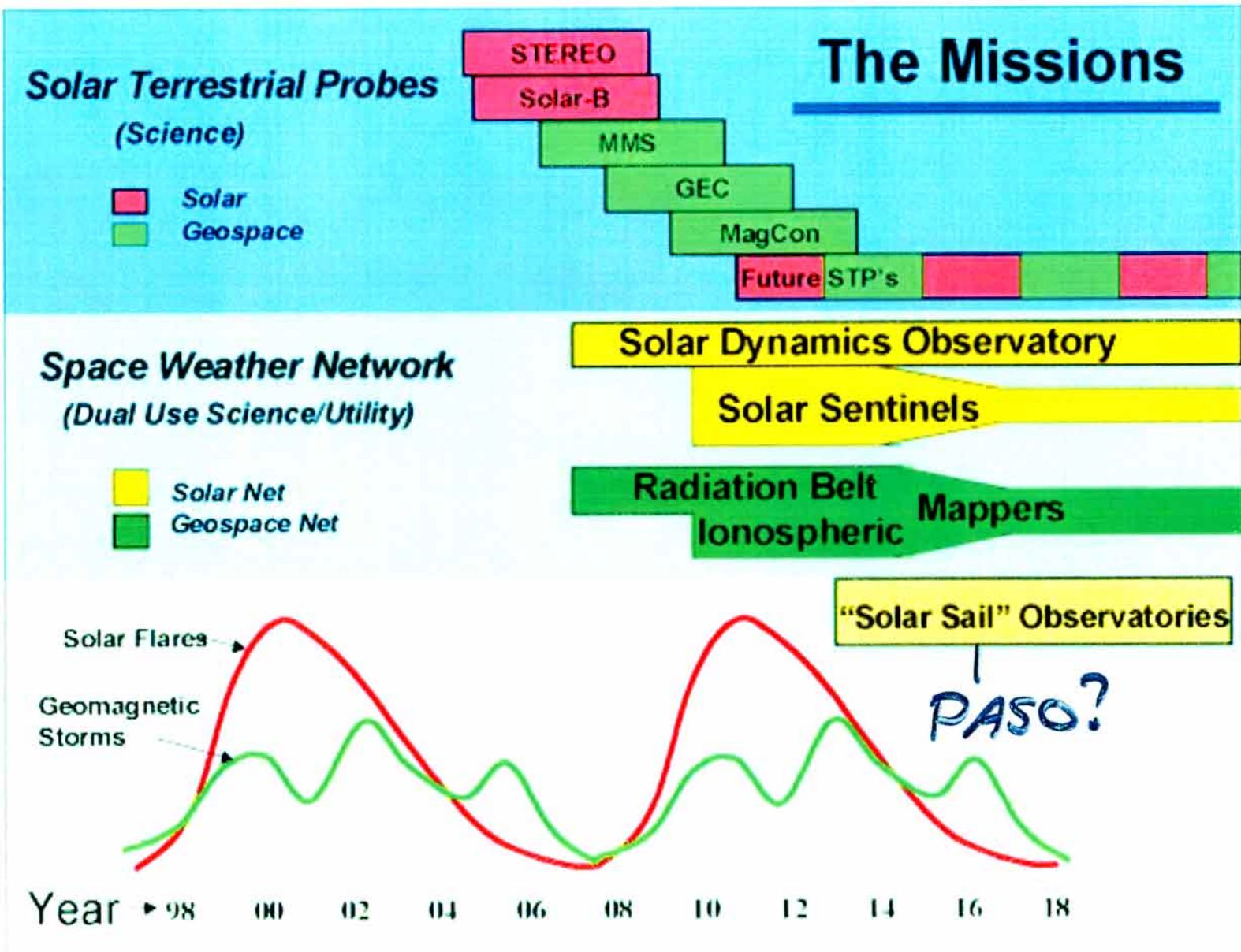
Daily Solar x-rays@GOES-8



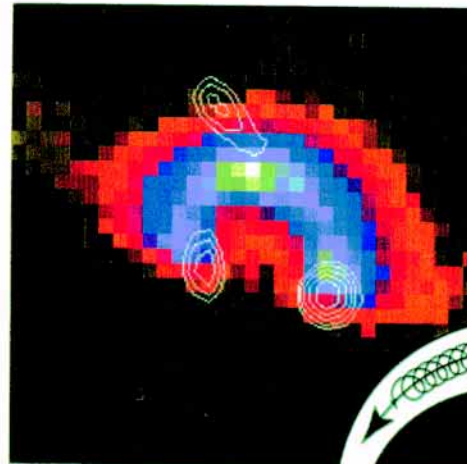
Instances of high solar activity
during solar minimum

SEC LAUNCH SCHEDULE PLANNED FUTURE MISSIONS

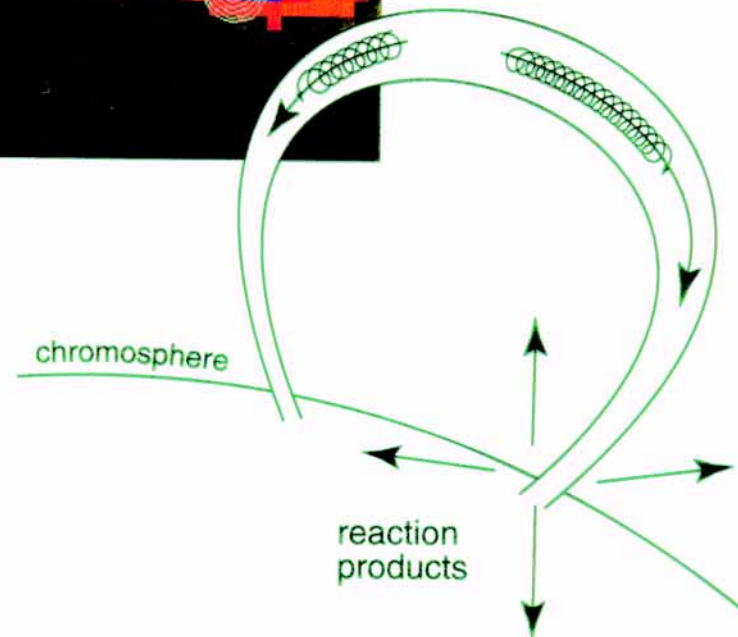




Neutron and γ -ray Production in Solar Flares



corona
e, p, ^3He , α , C, N, O, ...



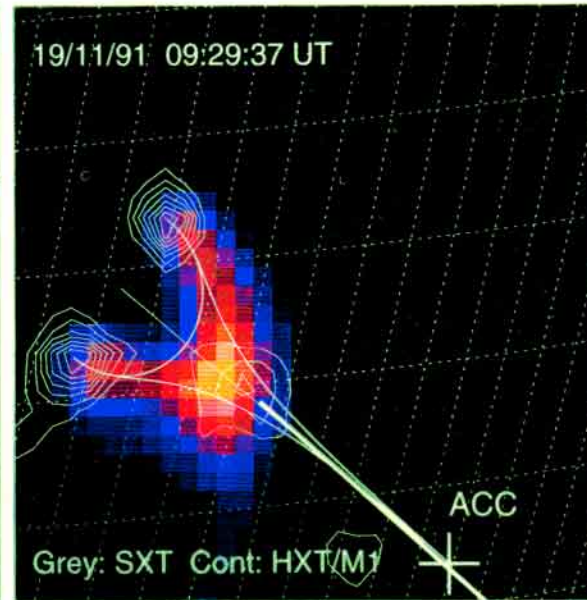
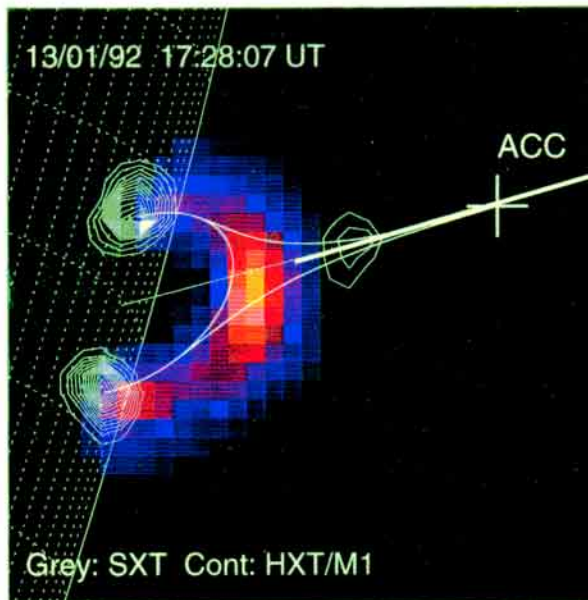
electrons: X- and γ -ray bremsstrahlung

ions:

- radioactive nuclei $\rightarrow e^+ \rightarrow \gamma_{511}$
- $\pi \rightarrow \gamma$ (decay, e^\pm bremsstrahlung)
- excited nuclei $\rightarrow \gamma$ -ray line radiation
- neutrons $\rightarrow \begin{cases} \text{escape to space} \\ 2.223 \text{ MeV capture line} \end{cases}$

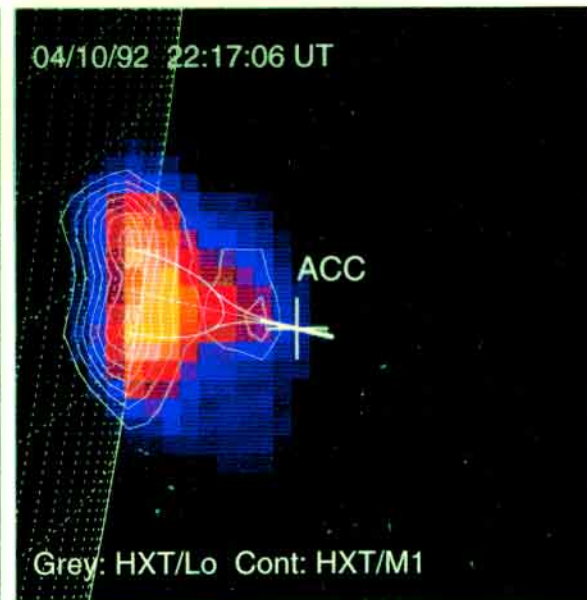
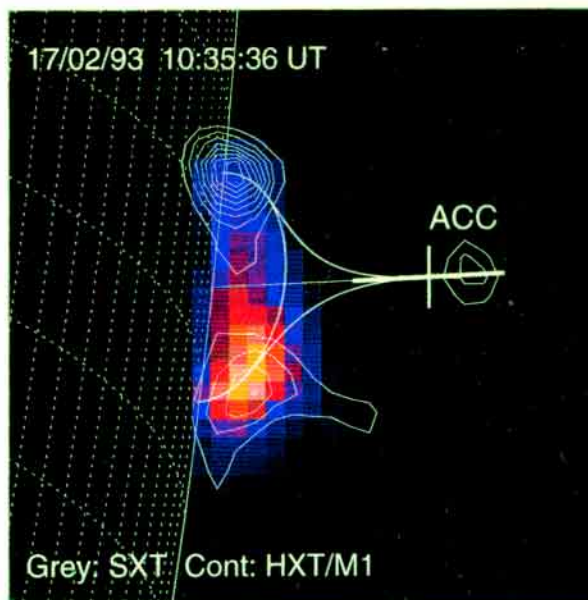
Acceleration region above flare loop?

~0.5 arcmin



YOHKOH
Images
Time of Flight
Acceleration
Region
(Achwander)

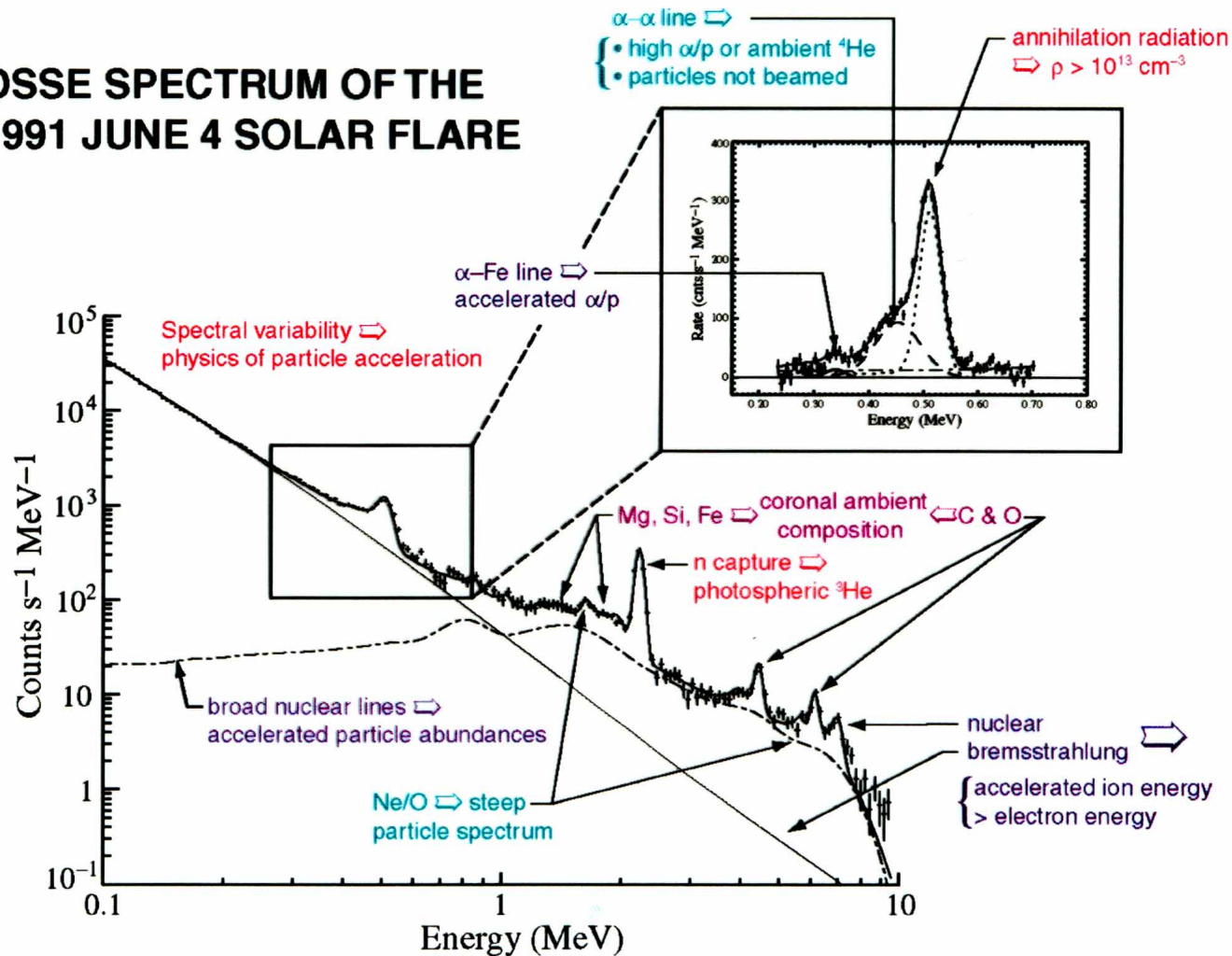
~0.5 arcmin



Measurement of Accelerated Particles at the Sun

Gerald Share and Ronald Murphy

OSSE SPECTRUM OF THE 1991 JUNE 4 SOLAR FLARE



STATISTICS OF HIGH-ENERGY GAMMA-RAY FLARES

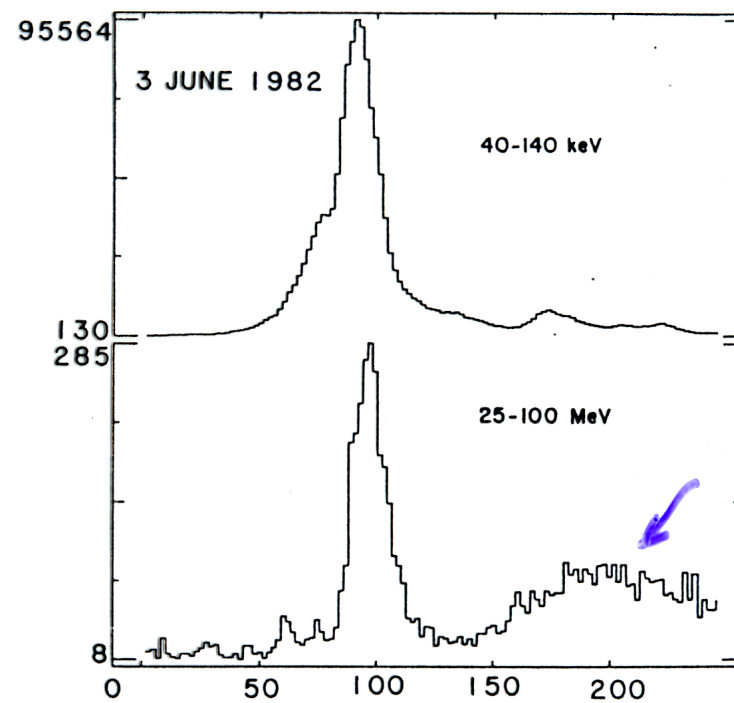
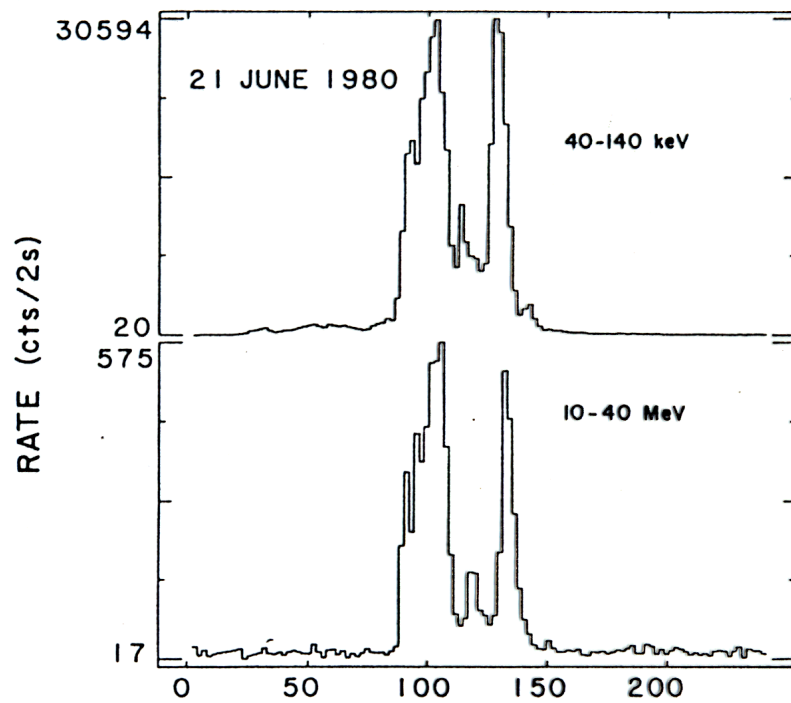
24 flares observed >10 MeV in over a solar cycle by the SMM spectrometer (~ 150 cm²). ~~1980-1989~~

18 of these flares were X-class X-ray flares and 6 were M-Class (1/10 soft X-ray flux of X-class).

Evidence for beaming of high-energy radiation comes from distribution of high-energy flares on the Sun and from hardening of spectra for flares near the limb (suggests a pancake distribution of radiation).

There were 88 X-class flares:

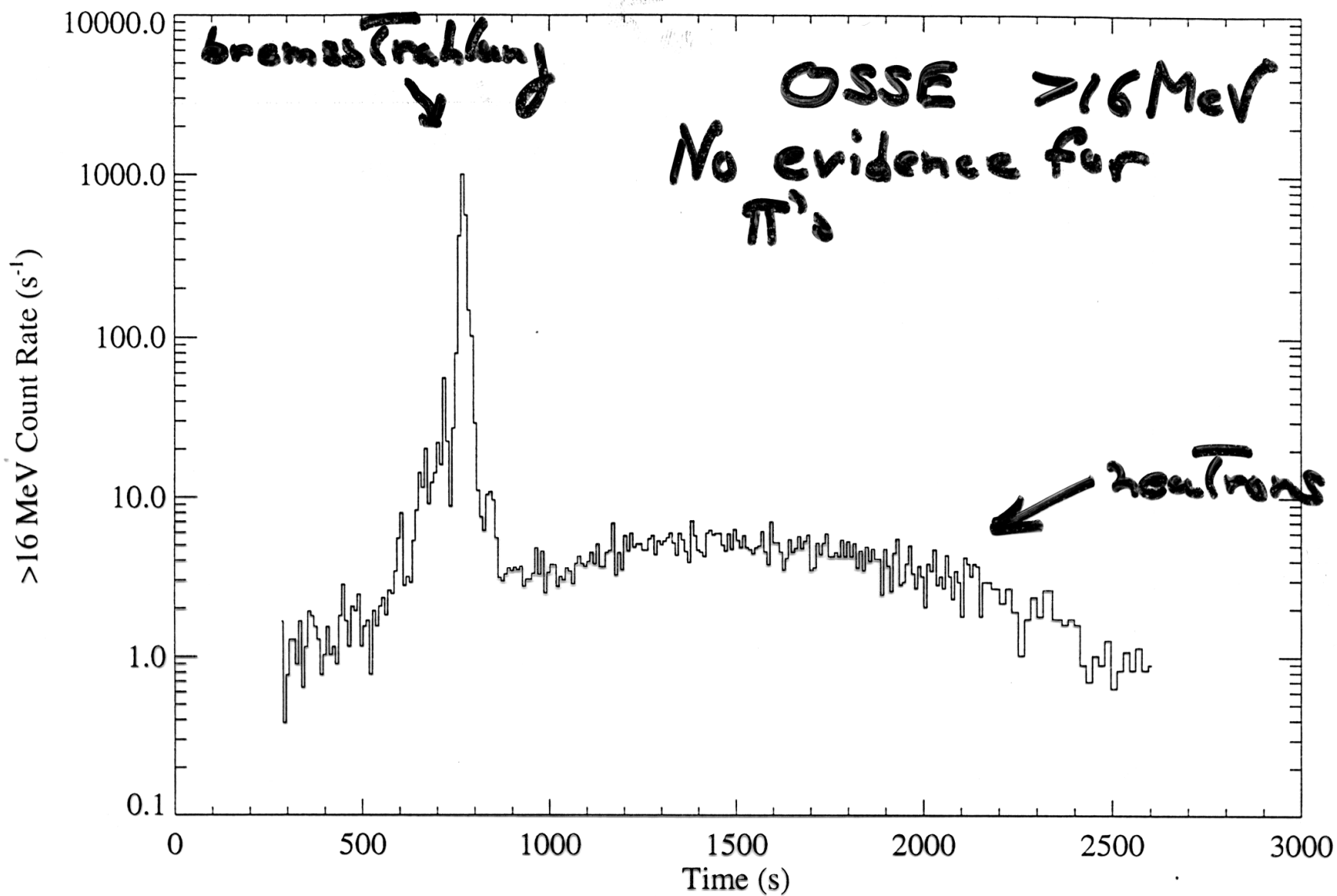
	Full sample >10 MeV		No >10 MeV
% observed at heliocentric angles $>60^\circ$	42 ± 8	71 ± 23	31 ± 8



π 's

Second stage of high-energy emission

June 4, 1991



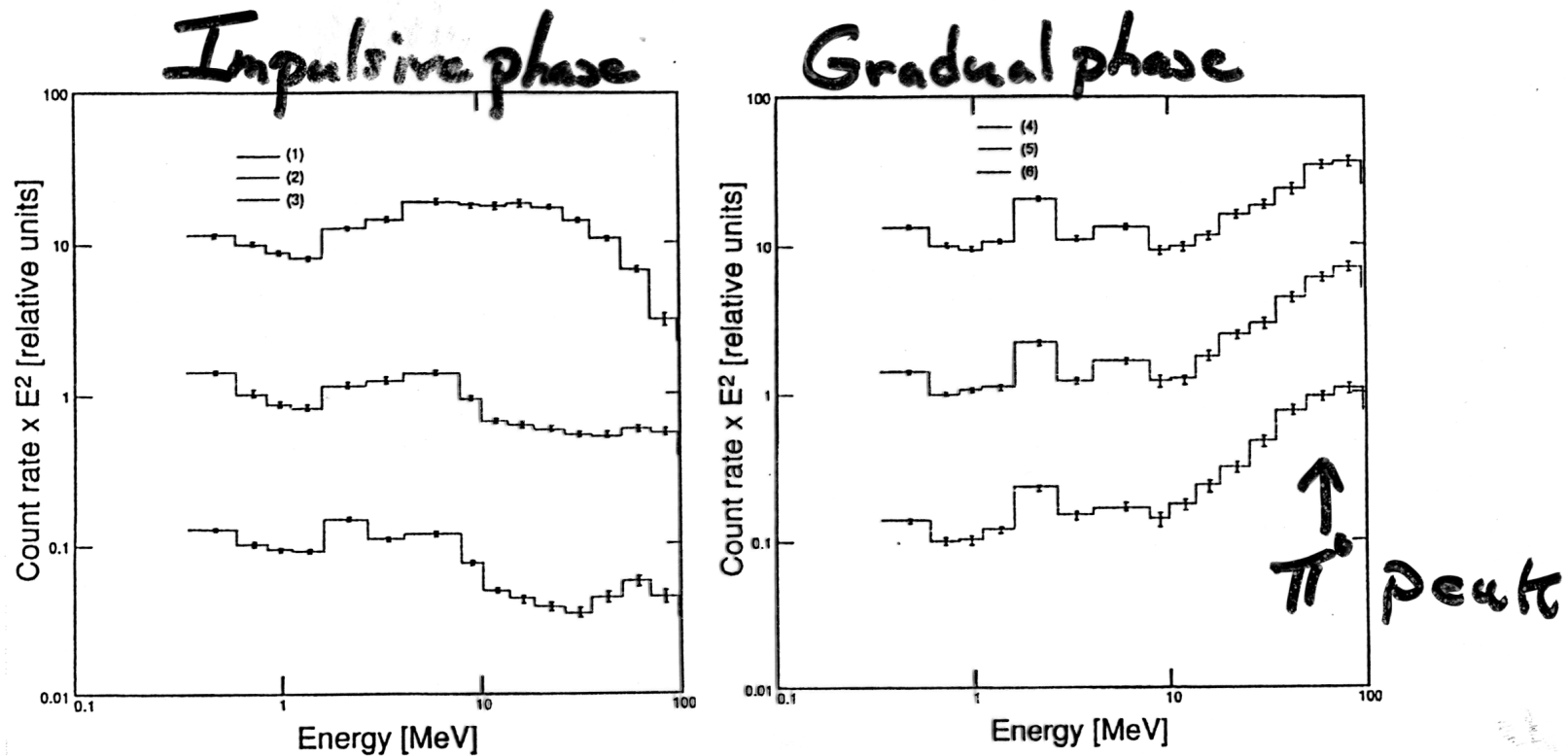


Figure 5. The γ -ray spectrum (weighted by E^2) from the (a, left) impulsive and transitional and (b, right) the gradual phase periods of the 24 May 1990 flare.

Debrunner et al.
Ryan

EGRET S.C.

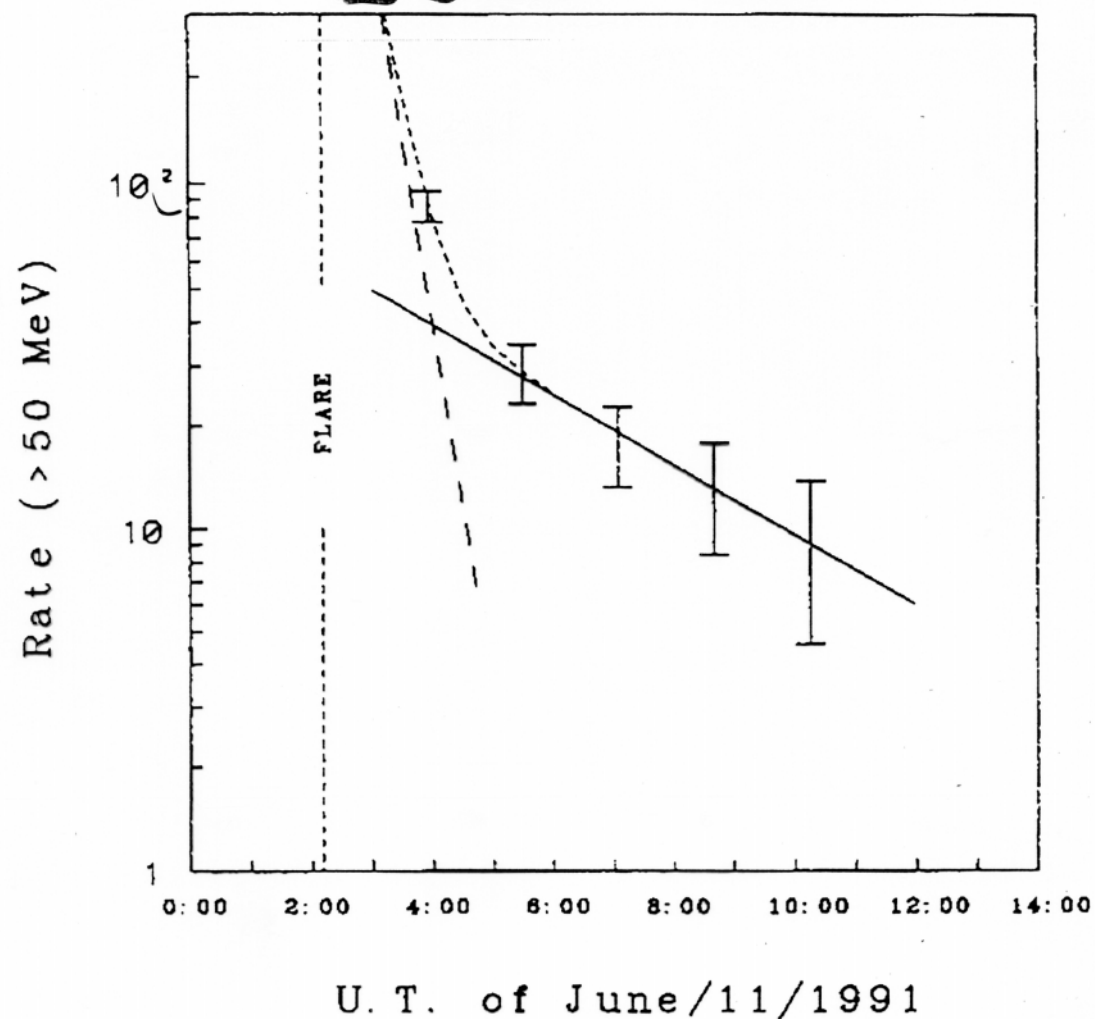
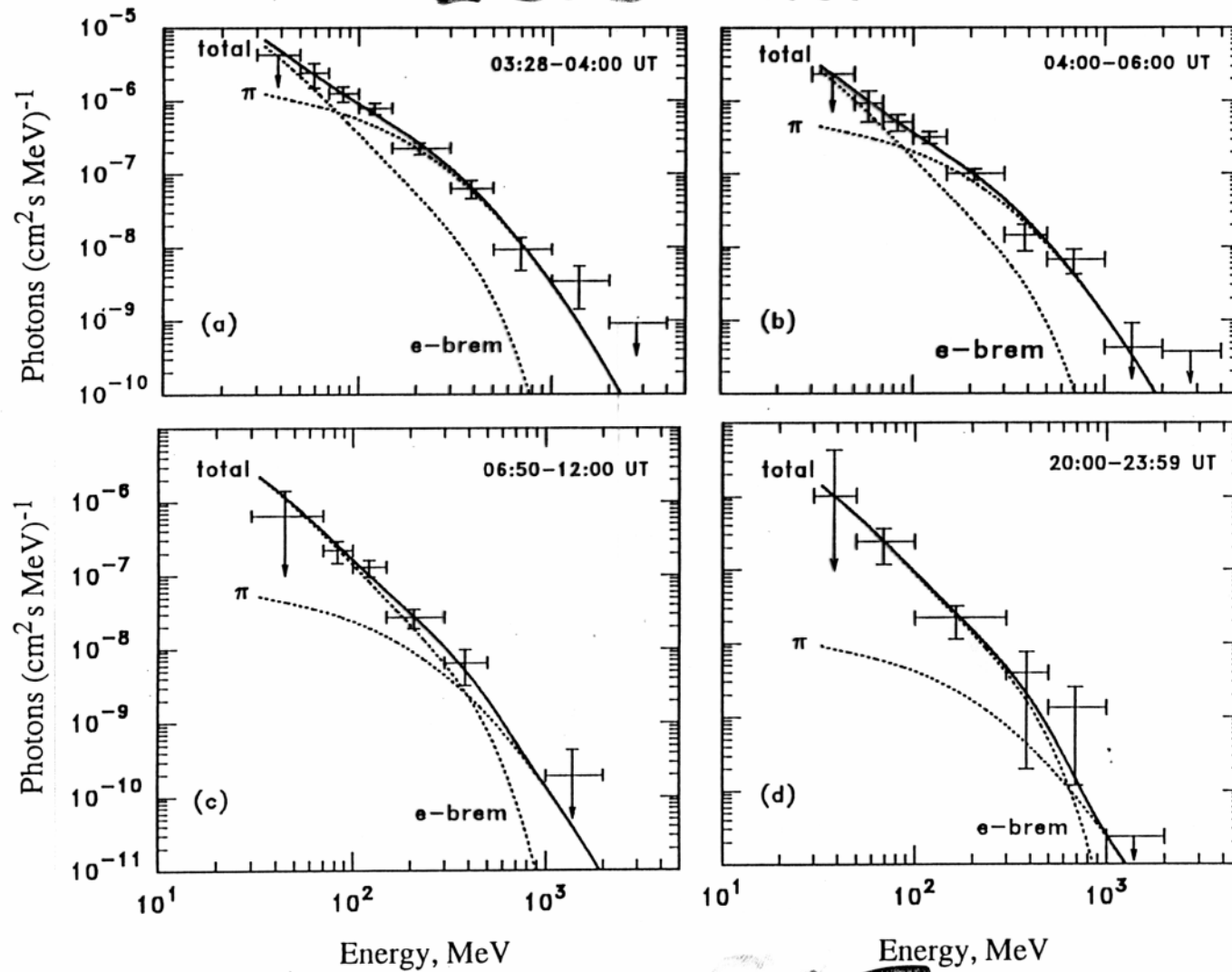


FIGURE 1. Time profile of the solar emission > 50 MeV on 1991, June 11, 1991. The two-component fit to the time profile is discussed in the text. The e-folding time constants derived are about 25 and 255 minutes.

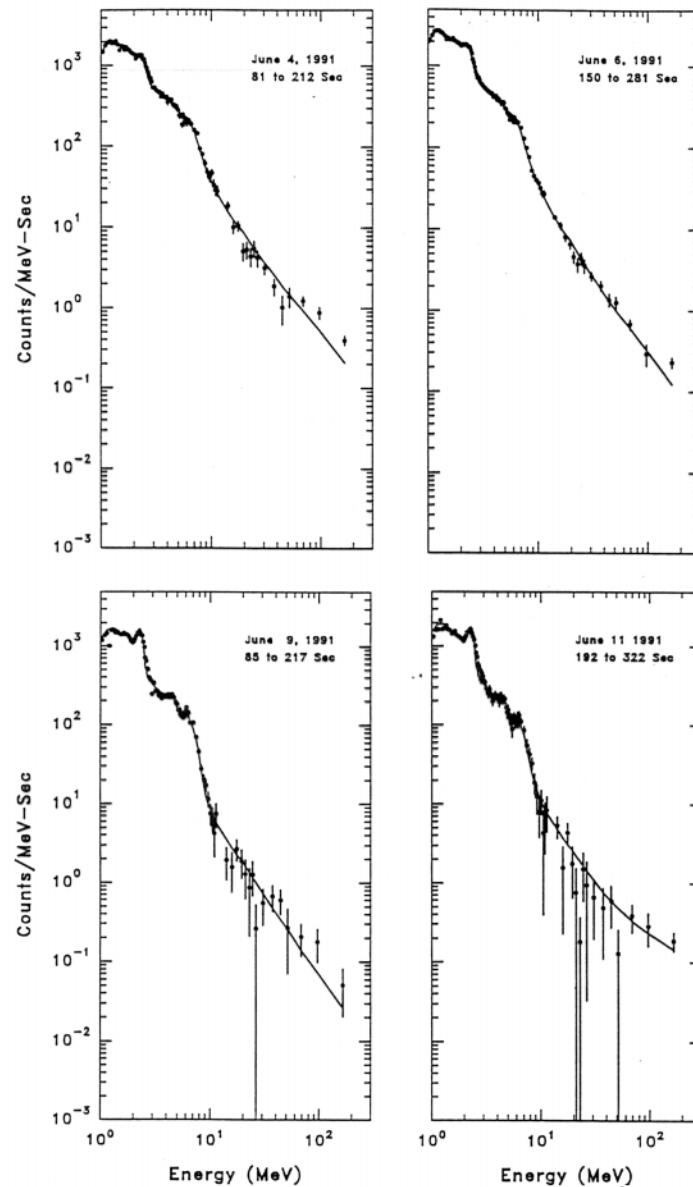
Kanbach et al.

EGRET S.C.



Spectral Evolution
(gradual phase only)

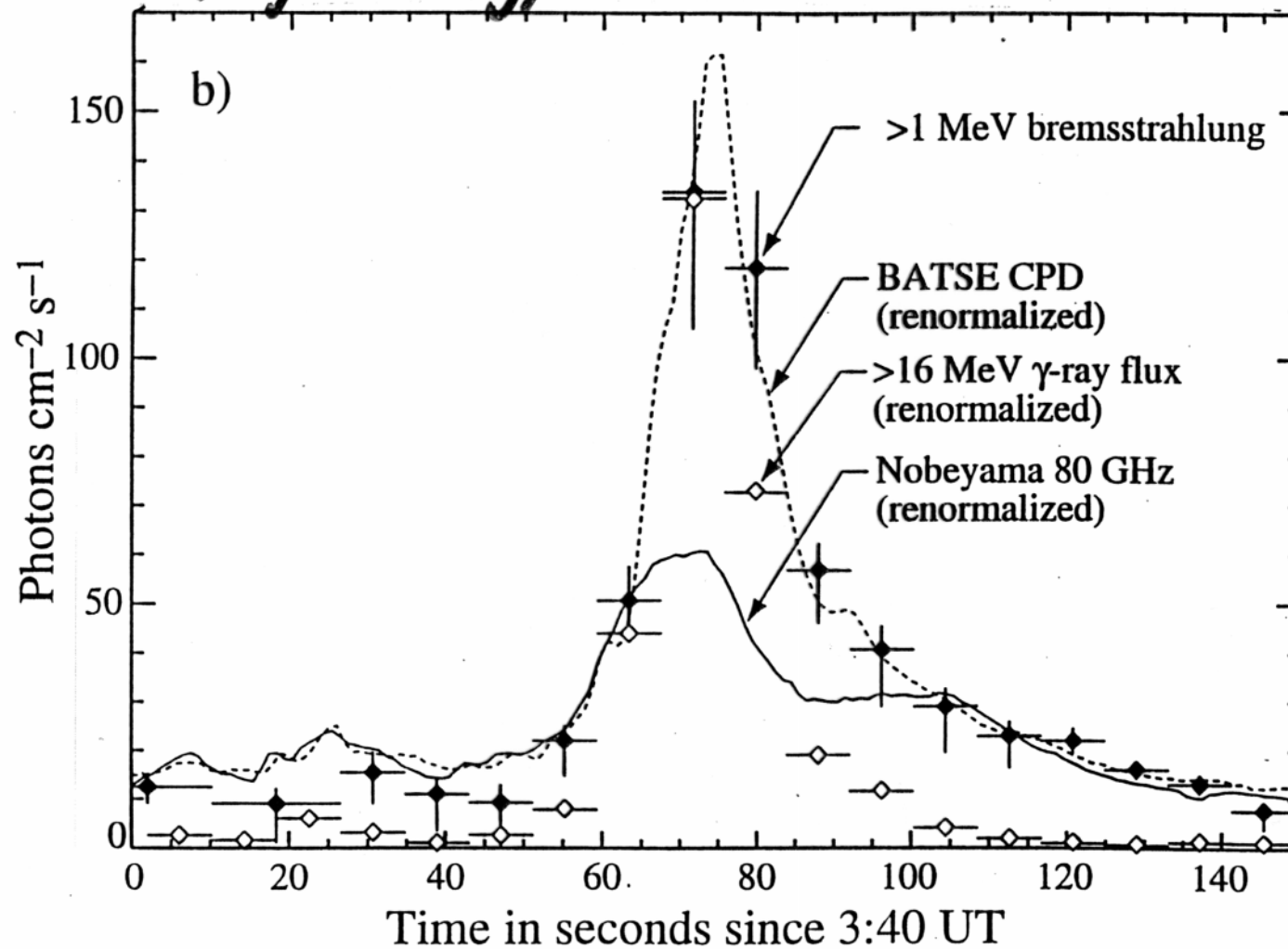
Bertoldi et al

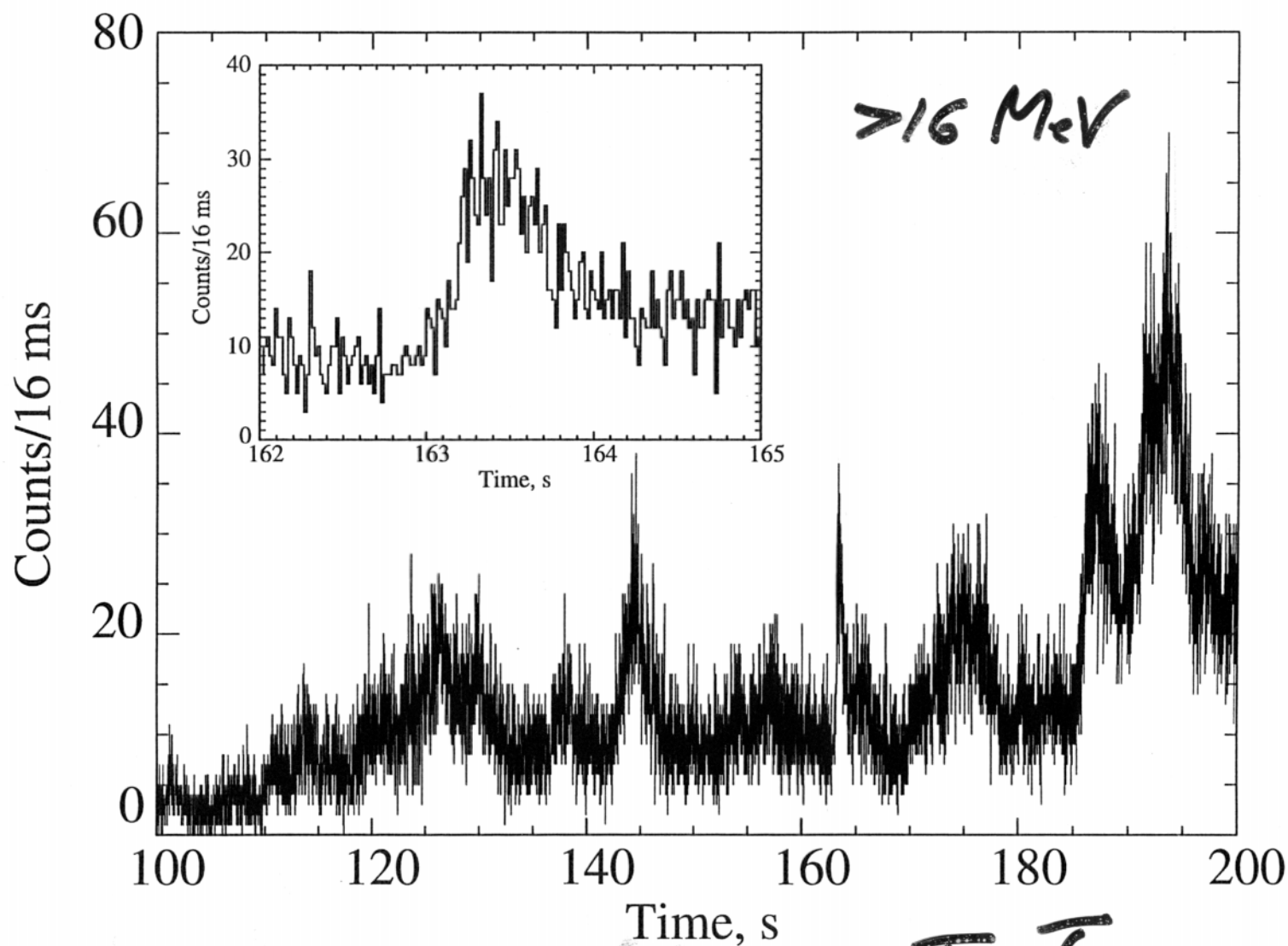


TASC spectral measurements
 Bertsch et al.
 < 200 MeV - close to impulsive phase

OSSE
Murphy et al.

High-energy electrons lost earlier





CSSE

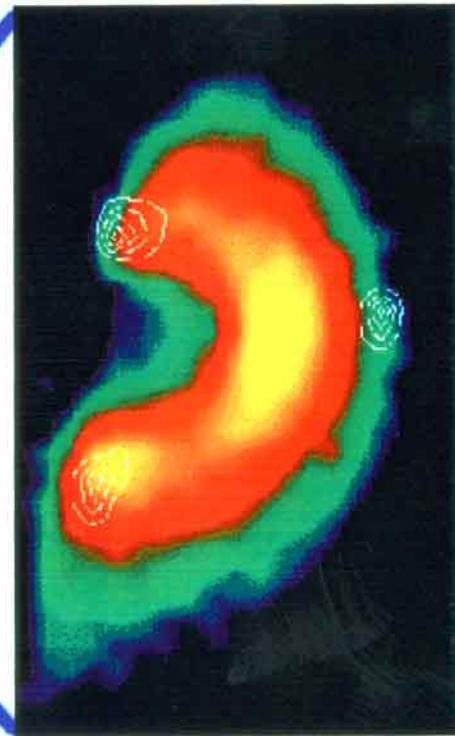
~ 0.1 sec temporal structure -
 \Rightarrow high energy acceleration time scale

LOCALIZATION OF THE FLARE REGION

30-60 arcsec localization can distinguish region where particles interact.

HESSI provides 36 arcsec resolution in 1 – 10 MeV region.

For 0.5° containment of GLAST at 1 GeV and good calibration on point sources, it is possible to determine whether the flare region is more extended than ~ 5 arcmin. Suggestions that high-energy particles interact over these scales.



30 arcsec

HESSI 1-10 MeV resolution 36 arcsec
GLAST location 0.5-1 arcmin

UNIQUE SOLAR PHYSICS CAPABILITIES OF GLAST

ONLY PLANNED HIGH-ENERGY MISSION THAT
CAN OBSERVE SOLAR FLARES

ABILITY TO DISTINGUISH ACCELERATED
ELECTRONS AND PROTONS FROM IMPULSIVE
TO GRADUAL PHASE

TIME SCALES FOR HIGH-ENERGY
ACCELERATION IN FLARES

UPPER BOUND TO ACCELERATION ENERGY IN
FLARES (>10 GeV?)

CONTINUOUS ACCELERATION OF PARTICLES
OR TRAPPING?

FUNDAMENTAL INFORMATION ON HIGH ENERGY
ACCELERATION IN ASTROPHYSICAL PLASMAS

COMPARISON WITH PARTICLE SPECTRA
OBSERVED IN SPACE

ARE HIGH-ENERGY PROTONS ACCELERATED IN
WEAK SOLAR FLARES? CR INTERACTIONS?

COMPARISON OF PION AND BREMSSTRAHLUNG
EMISSION → DIRECTIONALITY/TRANSPORT

SATURATION EFFECTS DURING FLARES

HIGH ENERGY EMISSION:

Maximum observed flux >10 MeV at peak of largest flares:
 $\sim 5 \gamma \text{ cm}^{-2} \text{ s}^{-1}$. This would yield a rate in each tower of
 $5 \times 10^3 \text{ s}^{-1}$ (assuming 100% efficiency). This would require
using only 4 towers to not exceed the 20 kHz event limit.

HARD X-RAYS AND LOW-ENERGY GAMMA-RAYS

Assume that Si is sensitive to photons >50 keV.

Flux >50 keV reaches levels of $10^4 \gamma \text{ cm}^{-2} \text{ s}^{-1}$ at the peak of
the largest flare observed to date (e.g. 4 June 1991).

→ Rate of 10^7 s^{-1} without attenuation in an individual tower.
What is maximum rate that a single silicon layer can handle?
0.1 MHz? If so we need to reduce the overall rate by at least
1 to 2 orders of magnitude. This would require turning off
the upper silicon layers of the towers.

→ What is the true event rate based on the criterion that 6
silicon layers must trigger? Energy dependence; chance
coincidences. Requires detailed calculations.

Observation of the impulsive phase of flares is important!
Acceleration time scales; rapid variability; electron/proton
ratio; location of high energy and low energy interaction
regions.

Fluxes drop within about 50 to 1000 s to levels where
GLAST can observe these large flares without any special
effort.

What can be done?

→ Ability to turn off 12 outside towers.

→ Ability to turn off upper layers of inside 4 towers. Can this be done automatically as rates exceed a certain level?

A 700 keV electron has a range of about 0.5 gm cm^{-2} in lead, or about 6 silicon layers (event criterion). Therefore let's consider the flux of gamma-rays $>0.8 \text{ MeV}$. For the largest flares the peak flux is $\sim 10 \text{ cm}^{-2} \text{ s}^{-1}$. Assuming an optimistic 50% efficiency for producing a GLAST event of 6 layers, yields an event rate of 5 kHz per tower. This event rate is right at the limit of GLAST's capability for 4 operating towers.

The next thing to consider is the reduction in overall rates in individual silicon layers. For example, assuming that the upper 20 layers (10 Pb layers) are turned off, how many photons would reach lower layers? For a $dN/dE \propto E^{-4.5}$ spectrum and incident $>50 \text{ keV}$ flux of $10^4 \text{ } \gamma \text{ cm}^{-2} \text{ s}^{-1}$ (largest X-class flare) the maximum rates in a single layer (assuming 100% conversion) are:

→ $\sim 1.5 \times 10^4 \text{ s}^{-1} < 150 \text{ keV}$

→ $\sim 2.5 \times 10^4 \text{ s}^{-1} > 150 \text{ keV}$

These rates can be handled by 0.1 MHz electronics. Can we reduce the number of dead layers?

Effect of using only lower layers: reduced angular resolution.